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Topic: Wind turbine technology - for offshore application. Wind resources and wake effects

The importance of accurate and reliable wind measurements at turbine hub-height for offshore wind farms

Rebecca Barthelmie, Ole Frost Hansen, Karen Enevoldsen and Rene Møller
Department of Wind Energy, Risø National Laboratory, 4000 Roskilde, Denmark
Email: R.Barthelmie@risoe.dk

Abstract
Although many other options such as use of existing onshore masts, satellites and buoys are often considered, the most accurate method of quantifying the wind resource at a wind farm location remains the traditional meteorological mast. There are disadvantages in terms of the expense and the delay involved while measurements are being made, but if measurements are made with care, invaluable information will be returned on the wind resource, wind speed profile and turbulence level which exists at the site. Risø has been making such measurements in remote and offshore locations for more than ten years. The satellite system used for data recovery provides near real time access to data for use in wind resource analysis and the system can also be used during construction of the wind farm to assess working conditions and in the post-construction phase to evaluate wind farm output and as part of a condition monitoring system for planning operation and maintenance.

Introduction
Risø has been monitoring wind resources and power output from offshore wind farms since 1993 (Barthelmie et al. 2005). In this period a considerable degree of expertise has been developed in optimising measurements and in using these databases to develop and validate models for offshore environments. Risø’s offshore monitoring strategy uses a fully automated satellite based retrieval which provides near-real time access to offshore data, even at remote stand-alone masts. Additional developments including online quality control are being developed. Access to quality measurements has provided an unrivalled basis for model development. In addition to predicting wind resources and turbulence for wind farm development, Risø has developed fatigue and extreme load models and has used measurements to develop and validate wake models for use in offshore environments (Frandsen 2001).
In situ measurements have been used in conjunction with satellite imagery (Hasager et al. 2004b) and with both sodar and lidar measurements (Antoniou et al. 2006), to optimise the height and accuracy of all four measurement types.

Comparison of methods

Different methods of providing resource data (Table 1) all have advantages and disadvantages. The main advantage of a traditional meteorological mast is the use of standard techniques which give highly accurate wind speed measurements if performed correctly at the site of interest and which are generally accepted by financial institutions when considering financing of offshore wind farms. The main disadvantages are the expense of erecting the mast structure particularly if measurements are made above heights of 50 m and the delay while the measurements are made.

Use of existing meteorological stations on land or reanalysis data sets are low cost options however the problem of extrapolating either from land or from a relatively coarse grid means that these will rarely be sufficiently accurate and the problem of extrapolating up or down to hub-height remains. Use of satellite images has a major advantage in that spatial information is accessible. The main disadvantages are that satellite images tend to be either readily and cheaply available for low resolution and low accuracy data which does not resolve wind speeds close to the coast (e.g. Quikscat) or moderately expensive to obtain and complex and time consuming to process (SAR) (Hasager et al. 2004a). In either case the accuracy of individual images is rather low. This aside, technological solutions for the temporal and spatial resolution of the data and for processing issues are rapidly being developed (Hasager et al. 2004b). Lastly use of sodar or Doppler lidar has been suggested as a method of monitoring hub-height wind speeds without the cost of a tall mast although a stable platform is needed for the measurements (Coelingh et al. 2003), (Barthelmie et al. 2003), (Antoniou et al. 2006). Aside from the moderately complex processing associated with sodar data, there are some issues remaining with the poor number of returns from greater heights and with low accuracy at high wind speed.

Low power satellite based datalogger systems

An outline of the satellite based datalogger system is given in Figure 1. The system has a number of advantages including provision of data online in near-real time (~30 minutes) and low power usage means it can be operated using a dry battery system with either a solar panel charger or battery replacement two to four times a year. The datalogger systems are simple to install and can be maintained by non-specialist personnel although maintenance requirements are low. Data recovery is high exceeding 95% for offshore stations in Denmark which were operated between 1999 and 2005. The datalogger can accept both analogue and digital inputs with a measurement rate up to 64 Hz. The datalogger/satellite systems have been used successfully for data recovery from offshore sites and the systems have also been used at remote sites world-wide via satellite or phone link. The data display is available via the world wide web providing straightforward access for most users. Both the graphical display and the data download can be password protected although providing the graphical data can be useful for local users e.g. sailing clubs. Having meteorology available online is also useful during construction and for maintenance planning. An example of the online data display is given in Figure 2 and the graphical data can be accessed at http://www.risoe.dk/vea-data/index.htm.

Table 1. Overview of different methods used to generate data for resource assessment offshore

Resource Method	Cost	Time investment	Height	Accuracy
Offshore met. mast	€400000	Installation (~few months, data collection ~1 year)	Up to hub height	~0.3 m/s
Reanalysis data	Free (non-commercial use)	Low	10 m or geostrophic	Low spatial resolution (2.5°x2.5°)
Existing onshore met mast	Free/low cost	Low	Up to hub-height	Difficult to extrapolate offshore
Satellite images	Low resolution –free. SAR ~€100's per image	High (Processing time and expertise)	Nominally 10 m	~2 m/s for 2-24 m/s (lower for average of multiple images) (2,3)
Sodar	~€50000	Needs stable platform. Data processing complex	Up to 150 m?	Low at high wind speeds. Poor number of returns at height

Figure 1. Overview of the satellite based data logger system.

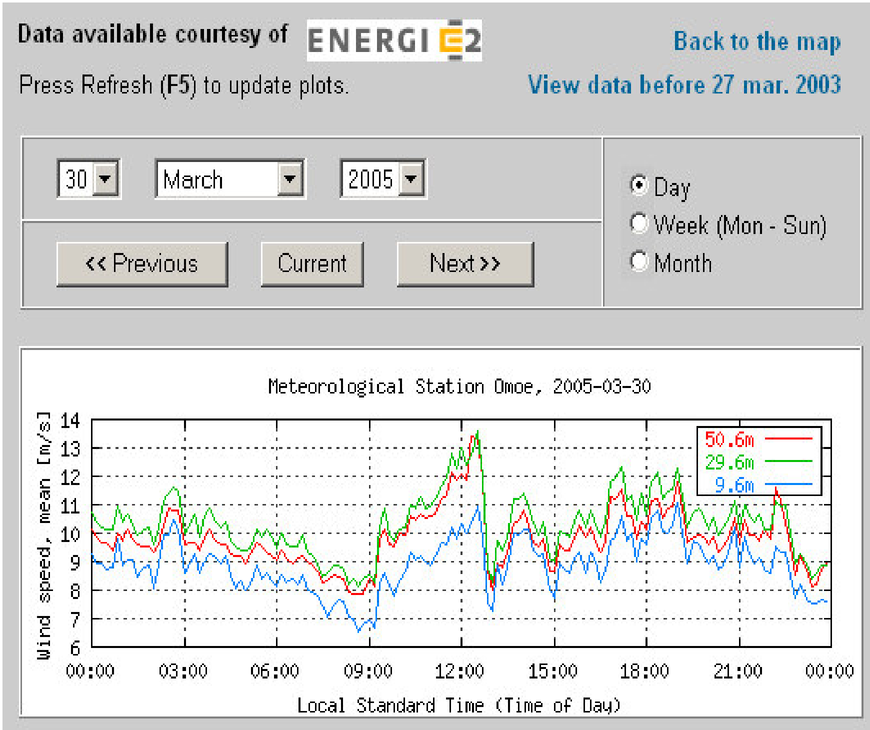

Figure 2. Example of the online data graphical display

Extrapolation to hub-height

If offshore wind speed measurements cannot be made at hub-height then smallest errors will result from extrapolation from the greatest height available (Figure 3). Extrapolation from heights below 10 m will be strongly affected by both roughness and stability. Extrapolation from 10 m upwards is not strongly affected by the choice of roughness length of water surfaces (Barthelmie 2001). Based on experience in Danish ‘inland’ seas, the logarithmic profile underestimates wind speeds if extrapolated from 10 m to hub-heights of 70 m and beyond. The slightly stable correction used in WAsP gives a reasonable approximation to the observed profile (Motta et al. 2005) (Figure 4).

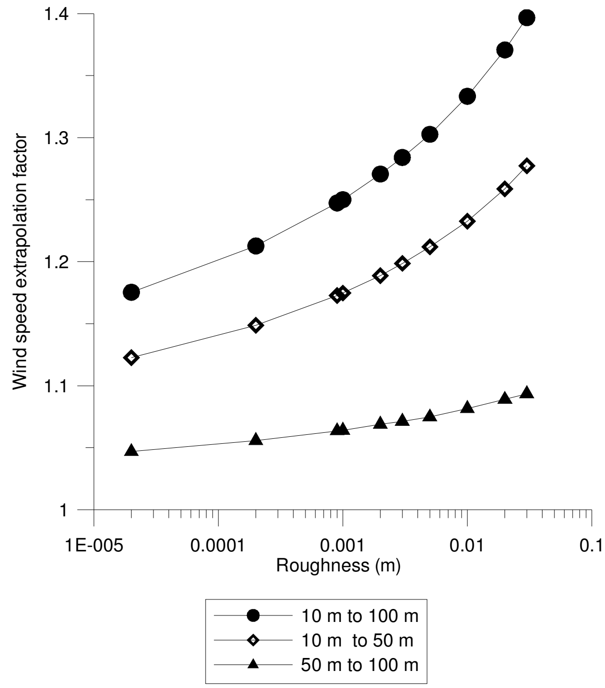

Figure 3. Factors needed to extrapolate wind speed from different heights assuming a logarithmic profile is valid.

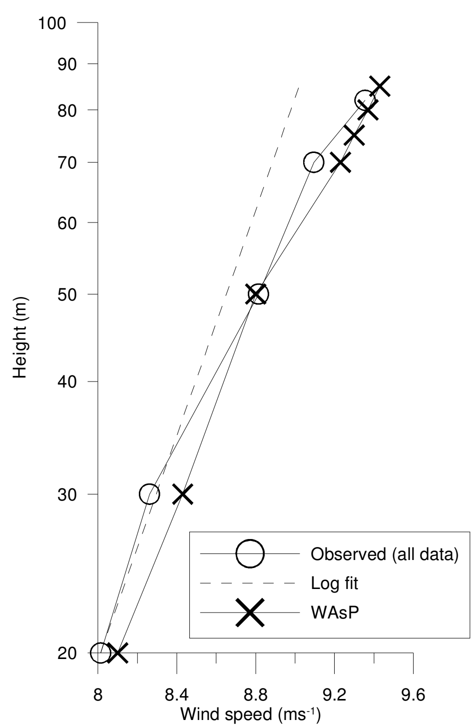

Figure 4. Offshore wind speed profile from a Danish site. Measurements in comparison with predictions using WAsP or the logarithmic profile.

Summary
Despite advances in use of some techniques such as sodar and satellite images, the most accurate and reliable method of determining average hub-height wind speeds for wind resource planning is use of a standard meteorological mast. This paper describes a low cost, low power system that has been developed for remote regions and has been shown to work reliably with high data recovery using a web-based data system with satellite transmission.

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